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EFFECTS OF UNIQUELY PROCESSED COWPEA AND PLANTAIN FLOURS ON WHEAT BREAD PROPERTIES

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ABSTRACT

The effect of incorporating uniquely processed whole-seed cowpeas or plantain flours at 10 or 20 g/100 g in all-purpose wheat flour on paste viscosity and bread-baking properties in a model bread was determined. Blanching plantains in hot water (100C) for 2 min increased final viscosity, reduced rapidly available glucose (RAG) from 8.5 to 4.5 μg glucose/mg, and increased bread loaf size. Whole-seed cowpeas containing the hulls processed by soaking in water (CPS), reduced raffinose significantly ($P < 0.05$), and α-galactosidase enzyme (CPE) treatment eliminated both raffinose and stachyose completely. CPS decreased RAG values from 8.5 to 2.8 μg glucose/mg. Incorporating cowpea flours into model wheat breads increased loaf size. CPE flours reduced bread loaf size and increased internal browning. These flours can be incorporated into all-purpose wheat flour bread up to 20 g/100 g with improved physical properties, and possibly better glycemic responses.

PRACTICAL APPLICATIONS

Plantain is an emerging source of slowly digestible starch, and cowpeas are rich in proteins and micronutrients that could help to combat metabolic syndrome. Unique processes that convert whole-seed cowpeas and plantains into dried flours will enhance commercial utilization of these tropical produce. Converting peak season cowpea and plantain into shelf-stable food powders will provide long-term storage, eliminate postharvest losses, add economic value, and enhance food safety and security in the tropics.

INTRODUCTION

Cowpeas (*Vigna unguiculata*) and plantains (*Musa paradisiaca normalis*) are tropical produce gaining worldwide acceptance for their nutritional and functional benefits, although greater commercial use is yet to be realized in the Western world (Prinyawiwatkul *et al.* 1997; Phillips *et al.* 2003; Hallen *et al.* 2004). Considerable research effort was expended in the 1990s to develop functionally acceptable cowpea and plantain flours by the United States Agency for International Development (USAID). The USAID funded Bean and Cowpea Collaborative Research in the past to promote the consumption of beans and cowpeas in the U.S.A. (Phillips *et al.* 2003). Current research interest is focused on expanding the use of cowpea and plantain flours as functional ingredients in food products for enhanced health benefits such as to lower glycemic potential and increased plant protein consumption.

For long-term preservation and ease of use, cowpeas and plantains are dried and milled, converting them into easy-to-use flours increasing their combined economic importance (Adeniji *et al.* 2007; Pacheco-Delahaye *et al.* 2008). For example, cowpea and plantain flours were used to manufacture extruded snack-type products (Oduro-Yeboah *et al.* 2014). Cowpeas are low in sodium (351 mg/kg) and are major sources of proteins (20–23%), iron (24 mg/kg), potassium (9.5 mg/kg), calcium (715 mg/kg) and other nutrients including vitamin A, ascorbic acid, thiamin, riboflavin, niacin, magnesium, phosphorus and dietary fiber (Phillips and McWatters 1991; Taiwo 1998; Adeniji *et al.* 2007). Products enriched with cowpea proteins were used to mitigate nutrition-impacted diseases such as diabetes by combining them with plantain to significantly increase insulin production and reduce postprandial insulin (Manders *et al.* 2005).

Plantain fruits are rich in dietary fiber (~9.0%) and resistant starch (~16%), and are good sources of vitamin A (carotene), vitamin B complex (thiamin, niacin, riboflavin and B6), vitamin C (ascorbic acid) and micronutrients, and they help reduce the blood sugar level (Ayodele and Erema 2010; Zakpaa *et al.* 2010). Specially processed plantain has been used to treat intestinal disorders in infants (Adeniji *et al.* 2007). Also, the glycemic response of processed unripe plantain (*M. paradisiaca*) assessed using 60 healthy subjects showed lowered postprandial serum glucose concentration (Manders *et al.* 2005). Recently, plantain flour was shown to offer potential for making good extruded healthy snack-type products in combination with oat fiber (Oduro-Yeboah *et al.* 2014).

Processing enhancements for cowpea and plantains include pretreatments to optimize production of flours to retain most of the functional and nutritional properties (Prinyawiwatkul *et al.* 1997). For example, germination, fermentation with α-galactosidase treatment or wet milling produces flours of varying functional quality (Prinyawiwatkul *et al.* 1996a,b,c; Kethireddipalli *et al.* 2002). The plantains could be boiled or roasted to enhance beneficial properties (Ayodele and Erema 2010). The production of cowpea and plantain flours with good reconstitution properties has a potentially large market as they can be readily incorporated in various formulations for improved health benefits (Oduro-Yeboah *et al.* 2014).

Glycemic index estimates the rapid increase in blood glucose following consumption of carbohydrate-containing foods, against the estimates through *in vivo* response to a reference food (Frost *et al.* 1993; Wolever *et al.* 1994). Although glycemic response requires human study to measure blood glucose response *in vivo*, however, good estimates of the glycemic response of a food product can be made *in vitro*. In this study, variously treated unripe plantains and cowpea seeds were converted into flours used to determine the rheological characteristics and glycemic potential of the flours without sensory analysis. The flours were substituted up to 20 wt% in model wheat bread.

MATERIALS AND METHODS

Cowpea Powder Processing

Cowpea beans were supplied by the California Bean Board (Pixley, CA). For only the dehulled sample reported in Table 1 (DC*), the cowpeas were soaked for 15 min in water and dried in a cabinet oven (Corbett Industries, Waldwick, NJ) for 3 h at 37.7C to loosen the hulls. After drying, the beans were passed through a laboratory brushing machine (LA-H, Westrup, Plano, TX) to remove the hulls and then passed through a grain aspirator (Grain Aspirator 63, Grainman, Miami, FL) to separate the hulls from the bean. For the hulled specimens used for viscosity and model breads, the whole-seed cowpeas were passed through a Perten 3600 Mill (Springfield, IL) to reduce their sizes (CPC), and dried in the oven at 50C for 12 h. The pulverized beans were treated at 50C for 2 h at 10:1 (water/bean, v/w) with slow agitation and were divided into two groups: soaked in water (CPS) or in pH 5.5 water with enzyme (0.038 mg of α-galactosidase [Amano Enzyme, Elgin, IL]/g beans) (CPE). The ground whole-seed cowpeas were used for analyses and substituted in model wheat bread. The hulls were left in to provide fiber and phytonutrients.

Plantain Powder Processing

Green plantains from Turbana Corporation (Coral Gables, FL) were purchased from a distributor, East Coast Tropicals (Philadelphia, PA). The unripe plantains were peeled and sliced (average thickness: 3.44 ± 1.34 mm) and stored in a plastic bag at 22C until treated (60 min). A portion, the control sample (PC*), was immediately placed into a 60C cabinet oven and dried for 16 h. The remaining material was either soaked in citric acid (0.5 M solution) at 25C for 2 min (PLCA) or blanched in 100C water for 2 min (PLB); both treatments were quenched by immersion in an ice bath at 0C. Immediately following the two treatments, all the samples were placed into the oven and dried at 60C for 16 h. After drying, the plantains were allowed to cool at 23C and then milled using a disc mill (Perten Instruments 3600 Laboratory Mill, Huddinge, Sweden).

Functional Properties of Cowpea or Plantain Flours and Blends

Rapid Visco Analyzer (RVA). The pasting properties of the powders were determined using the RVA4 (Newport Scientific Pty, Ltd., Warriewood, NSW, Australia). The 3.5 g of sieved (using a #35 sieve) powder was added to water (approximately 25.4 g); the amount was adjusted according to the moisture content of the powder to make up a 14% moisture paste. RVA standard starch testing method, Standard 1, was used to determine the peak viscosity, the point at which pasting occurs. The same RVA assay procedure was used for all individual cowpea or plantain powders and their respective blends with all-purpose wheat flour mixed 50:50 (w/w).

TABLE 1. PROXIMATE ANALYSIS OF PLANTAIN AND COWPEA FLOURS

	Plantain			Cowpea			
	PC*	PLCA	PLB	DC*	CPC	CPE	CPS
Protein (%)	3.35	3.08	3.08	21.59	23.05	23.70	23.54
Moisture (%)	3.67	3.81	5.49	10.29	7.81	5.94	5.99
Fat (%)	1.24	1.36	0.88	0.89	1.92	2.27	2.30
Fiber (%)	0.51	0.46	0.62	1.19	2.46	1.98	1.53
Ash (%)	2.61	2.15	2.40	3.54	3.55	3.67	3.70
Starch (%)	69.27	65.97	63.74	26.45	31.59	38.89	38.15
Fructose (%)	4.04	2.60	0.73	0.09	0.11	2.32	2.05
Glucose (%)	4.27	4.56	0.87	0.83	0.43	4.37	2.64
Sucrose (%)	1.02	0.00	6.06	2.83	2.17	0.00	0.00
Maltose (%)	0.00	0.00	0.00	0.15	0.35	0.19	1.00
Raffinose (%)	n/a	n/a	n/a	0.24	0.29	0.00	0.04
Stachyose (%)	n/a	n/a	n/a	1.67	1.50	0.00	0.11
Iron (ppm)	<10	<10	<10	31.0	67.50	75.50	80.50
Magnesium (ppm)	1,000.0	850.0	890.0	1,684.0	1,670.0	1,700.0	1,710.0
Zinc (ppm)	<10	<10	<10	37.0	37.50	42.00	38.50
Vitamin A (IU/100 g)	379.50	276.50	684.0	0.00	0.00	0.00	0.00
Vitamin C (mg/100 g)	7.77	16.80	3.22	<0.5	<0.5	<0.5	<0.5
Vitamin E (IU/100 g)	0.45	0.43	0.57	<0.1	<0.1	<0.1	<0.1

Plantain PSE: protein: 0.14, moisture: 0.85, fat: 0.25, fiber: 0.08, ash: 0.19, starch: 2.29, fructose: 1.36, glucose: 1.67, sucrose: 2.66, maltose: 0.00, iron: –, magnesium: 63.68, zinc: –, vitamin A: 173.2, vitamin C: 5.78, vitamin E: 0.06; cowpea PSE: protein: 0.70, moisture: 1.55, fat: 0.48, fiber: 0.50, ash: 0.07, starch: 4.62, fructose: 1.04, glucose: 1.60, sucrose: 1.20, maltose: 0.35, raffinose: 0.1, stachyose: 0.75, iron: 16.12, magnesium: 18.54, zinc: 2.92, vitamin A: 0.00, vitamin C: –, vitamin E: –.

CPC, whole-seed cowpea; CPE, cowpea soaked in α-galactosidase enzyme; CPS, cowpea soaked in water; DC*, dehulled cowpea; PC*, plantain control; PLB, plantain blanched in 100C water; PLCA, plantain soaked in citric acid.

Glycemic Index. The rapidly available glucose (RAG), glucose available in 20 min, and slowly available glucose (SAG), glucose available in 120 min, were determined as *in vitro* predictors of the glycemic response of bread samples. The glycemic response was measured by *in vitro* digestion of ground specimens of all-purpose wheat flour bread baked with cowpeas or plantains were measured using methods described by Englyst *et al.* (1996). For the hydrolysis, 0.8–1.5 g milled specimen was incubated with enzyme cocktail consisting of 2.8 mL amyloglucosidase (Sigma-Aldrich, St. Louis, MO) and 8.0 mL deionized water (140 AGU/mL amyloglucosidase), 3.0 g pancreatin (Sigma-Aldrich) and 20 mL sodium acetate buffer (prepared by dissolving 16.6 g sodium acetate trihydrate; Sigma-Aldrich) in 250 mL saturated benzoic acid and made up with deionized water to 1 L. RAG was measured with 0.5 mL hydrolysate removed after 20 min incubation at 37C. Another 0.5 mL was removed after 120 min of incubation at 37C for determining SAG. RAG values are highly correlated to the glycemic index when tested against human subjects (Englyst *et al.* 2003). After the hydrolysis and digestion procedure, glucose values for RAG and SAG were determined using YSI analyzer model 2700 Select (YSI Life Sciences, Yellow Springs, OH). Glycemic potential was determined as the ratio of glucose in approximately 1 g carbohydrate measured on a dry basis according to Hardacre *et al.* (2006) except that carbohydrate was determined by the phenol-sulfuric acid assay (DuBois *et al.* 1956). The values for glucose, fructose, sucrose, lactose and maltose were determined using the Free Sugar Profile (Kakehi and Honda 1989).

Stachyose and Raffinose Analysis. The values for raffinose and stachyose were determined using the methods described previously (Janauer and Englmaier 1978; Knudsen and Li 1991). Starch values were determined using a modified base method for the Sigma starch assay kit (product code STA-20) according to Approved Methods No. 76-13, American Association of Cereal Chemists (AACC 2000).

Mineral Analysis. Iron, magnesium and zinc were determined using inductive coupled plasma using optical emission spectroscopy and flame atomic absorption spectroscopy for elemental mineral analyses following AOAC Official Methods 985.01 (A, B, D) and AOAC 968.08 (AOAC 2006).

Proximate Analysis. Proximate analysis of breads was determined following AOAC methods 990.03 Total Nitrogen or Crude Protein, 942.05 Ash Determination, 978.10 Crude Fiber, 934.01 Moisture and 954.02 Crude Fat by Acid Hydrolysis (AOAC 2006).

Vitamin Analysis. Carotenoids (AOAC: 2005.07), beta-carotine (vitamin A), were determined following an enzymatic digestion and homogenization with tetrahydrofuran to extract the carotenoids. The extract was filtered and quantified using reverse phase high performance liquid chromatography (HPLC) with UV-Vis detection (AOAC Method 2005.07). Ascorbic acid (vitamin C) was determined following the AOAC methods (967.22 and 984.26*) with modifications. The samples were extracted in a methanol/metaphosphoric acid solution. The ascorbic acid is converted to dehydroascorbic acid, which reacts with ortho-phenylenediamine to form a fluorophore whose intensity is proportional to vitamin C concentration. A blank was run simultaneously on each sample to determine the level of background fluorescence. The total vitamin C content was calculated based on a standard curve. Vitamin E content was determined following the AACC method 88-06. Samples were saponified by refluxing in ethanolic KOH, then the extracts were diluted to known volumes and subjected to reverse phase HPLC analysis using a C8 column with isocratic elution. Alpha-tocopherol is detected using a fluorescence detector and the results are compared with a standard curve.

Baking. Based on the recipe for wheat bread, 418 g of all-purpose wheat flour (or substituted with either cowpea or plantain flour at 10 or 20% wt%) was blended with 18 g of sugar, 11 g of skim milk powder, 21 g of salt-free butter, 7.5 g of NaCl, 8.5 g of commercial dried yeast and 295 mL of deionized water. The breads were baked using an automatic home bakery machine (Panasonic SD-YD250, Secaucus, NJ) following the rapid bake function allowing the dough to mix, rise for 1 h and then bake for 1 h.

Texture Analysis of Bread. The texture analysis of the breads were conducted using a TA-XT2 texture analyzer (Stable Micro Systems, Surrey, UK) fitted with a 500-N load cell, running at a cross-head speed of 2.0 mm/s, and fitted with a 6-mm cylindrical probe. Firmness (N), the peak force required to compress the bread specimen to 60% of the original bread slice thickness (25.4 mm), was measured. Data reported are averages of 10 specimens sampled.

Color Analysis of Bread. The color analysis of bread slices was completed using a Colorquest XE (Hunter Labs, Reston, VA) colorimeter set to reflectance specular infrared mode using a 0.95-cm aperture opening. L^*, a^*, b^* and ΔE values were recorded in triplicate.

Water Activity of Bread. To determine water activity, bread slices were ground, and the resulting crumbs were placed into a plastic sample cup and into the AquaLab 4TE (Decagon Devices, Pullman, WA) water activity meter, where they were measured in triplicate.

Statistical Analysis. The analysis of variance for the data generated for the studies were analyzed using the Statistical Analysis Systems version 9.2 software package (SAS, Cary, NC). Significance of treatment means was tested at 5% probability level using Duncan's new multiple range test, and standard error values are listed in the table footnotes.

RESULTS AND DISCUSSION

Plantain Properties

The proximate composition of cowpea and plantain flours developed using different processes are presented in Table 1. Two plantain flours, one blanched in 100C water for 2 min (PLB) or soaked in citric acid for 2 min at 25C (PLCA), showed similar values for protein, fat, fiber and ash content. Blanching in hot water increased the moisture content. Loss of starch, fructose and glucose was observed for blanched plantain while sucrose increased following blanching treatment (Table 1). Maltose, raffinose and stachyose were not detected in the plantain flours. Citric acid treatment increased vitamin C substantially, but decreased magnesium. Pacheco-Delahaye *et al.* (2008) showed that the drying of plantain flours affected water absorption or swelling and viscosity properties. It was reported that dry heat and moist heat processing of plantain altered the physical form of the carbohydrates and affected amylase digestion (Ayodele and Erema 2010). Adeniji *et al.* (2007) showed that blanching and cold water treatment reduced sugar and protein content. Other researchers showed that blanching changed the proximate composition, pasting and sensory qualities of plantain (*M. paradisiaca*) (Oluwalana and Oluwamukomi 2011).

The pasting properties of variously treated plantain flours are presented in Table 2. Blanching plantain in hot water decreased breakdown viscosity and pasting temperature, while trough, final and setback viscosity of the resulting pastes increased. In contrast, soaking in citric acid decreased peak, trough, final and setback viscosity significantly. Compared with all-purpose wheat flour, the plantain flours were higher in paste attributes, except breakdown viscosity and pasting temperature. When the blanched plantain flours were blended 50:50 with all-purpose wheat flour, paste

TABLE 2. RVA PASTING PROPERTIES OF PLANTAIN FLOURS (100%) AND ALL-PURPOSE WHEAT FLOUR BLENDED WITH PLANTAIN FLOURS (50/50)

Process	Peak Pa·s	Trough Pa·s	Breakdown Pa·s	Final Pa·s	Setback Pa·s	Pasting temperature C
Plantain control (PC*)	8.91	4.10	4.81	5.82	1.72	70.4
Blanched (PLB)	9.10	6.39	2.71	10.18	3.80	61.0
Citric acid (PLCA)	6.56	1.96	4.60	2.90	0.93	66.6
50:50						
Flour (100%)	1.33	0.37	0.95	1.00	0.62	61.3
Flour/PLB 50:50	2.27	1.42	0.86	2.62	1.20	65.6
Flour/PLCA 50:50	4.44	2.38	2.05	4.06	1.67	74.0

PSE blanched: peak: 0.94 Pa·s, trough: 0.47 Pa·s, breakdown: 0.55 Pa·s, final: 0.71 Pa·s, setback: 0.25, pasting temperature: 2.78C; PSE citric acid: peak: 0.47 Pa·s, trough: 0.19 Pa·s, breakdown: 0.28 Pa·s, final: 0.23 Pa·s, setback: 0.07 Pa·s, pasting temperature: 5.60C. PSE all-purpose flour/blanched: peak: 0.38 Pa·s, trough: 0.21 Pa·s, breakdown: 0.18 Pa·s, final: 0.38 Pa·s, setback: 0.17, pasting temperature: 3.60C; PSE all-purpose flour/citric acid: peak: 1.38 Pa·s, trough: 0.67 Pa·s, breakdown: 0.69 Pa·s, final: 1.17 Pa·s, setback: 0.47 Pa·s, pasting temperature: 20.86C.
PC*, plantain control; PLB, plantain blanched in 100C water; PLCA, plantain soaked in citric acid; RVA, rapid visco analyzer.

properties were reduced (Table 2) compared with citric acid-treated flour blended with all-purpose wheat flour except for setback viscosity and pasting temperature, but the blends were still higher in paste properties than all-purpose wheat flour alone. The pasting properties of plantain portend differences in bread-baking properties when substituted partially for flour in bread. Oluwalana and Oluwamukomi (2011) showed that pasting peak viscosity was lower for blanched plantain flour, and the final viscosity was highest for the unblanched plantain. In our study, blanching of plantain before drying into flour improved physicochemical and pasting qualities of its flour. Pregelatinization of the starch in the flour at higher blanching temperature may result in lower setback values. The high setback value and breakdown viscosity for the samples at low blanching temperature indicates that their paste would have a lower stability against retrogradation than those at high temperature.

Cowpea Properties

The proximate composition of the cowpea products, including cowpea with the hull (CPC), soaked in water (CPS) and α-galactosidase enzyme (CPE) were compared with dehulled cowpea flour (DC), are presented in Table 1. Cowpea hull removal decreased protein, fat, fiber and iron content (Table 1). When compared with the control (CPC), the fructose and glucose values increased and sucrose, raffinose and stachyose values decreased for α-galactosidase enzyme-treated cowpea flour (CPE). However, as there were no significant differences between CPE and CPS proximate values, the change in carbohydrate content cannot be attributed to α-galactosidase enzymatic activity. Carbohydrate changes in CPE and CPS were probably caused by native enzymes when cowpeas were soaked in water. Previous studies have shown that the scale-up production of flour essentially free of flatulence-causing oligosaccharides is feasible and would stimulate increased utilization of cowpeas (Prinyawiwatkul *et al.* 1996c). Our study has shown that functional characteristics of cowpea flours were affected greatly by various processing treatments during flour preparation. Previously, Prinyawiwatkul *et al.* (1997) showed that soaking and fungal fermentation of cowpeas had less impact on flour functionality compared with boiling, and that complete elimination of sucrose, raffinose and stachyose was observed in flours made from cowpeas fermented for at least 15 h at 30C. Cowpea flours free of flatulence-causing oligosaccharides was successfully prepared from nondecorticated cowpeas using a solid substrate fermentation with *Rhizopus microsporus* (Prinyawiwatkul *et al.* 1996a).

The pasting properties of processed cowpea flours compared with all-purpose wheat flour are presented in Table 3. In particular, CPS increased in final and setback viscosity values. When these processed cowpea flours were blended with all-purpose wheat flour (50:50), the viscosity values were similar to all-purpose wheat flour. Although the trough and setback viscosity values remained higher, the bread-baking potential of the treated cowpea flours showed possibility for expansion to the same extent as all-purpose flour. Chinma *et al.* (2012) demonstrated the cookie-making potentials of unripe plantain flours blended at different proportions in cookie batter resulted in higher peak viscosity, trough, final and setback viscosity values than all-purpose flour. Gomez *et al.* (2008) reported a decrease in peak viscosity, break down and setback value when chickpea flour replaced wheat flour in cake. Substituting cowpea flours for wheat decreased starch content and affected

TABLE 3. RVA PASTING PROPERTIES OF COWPEA FLOURS (100%) AND ALL-PURPOSE WHEAT FLOUR BLENDED WITH COWPEA FLOURS (50/50)

Treatment (100:0)	Peak	Trough	Breakdown	Final	Setback	Pasting temperature
Cowpea	Pa·s	Pa·s	Pa·s	Pa·s	Pa·s	C
Control (CPC)	1.85	1.61	0.27	1.61	0.001	70.1
Water (CPS)	2.91	2.85	0.07	5.00	2.16	61.1
Enzyme (CPE)	2.63	2.21	0.42	3.42	1.21	79.9
50:50						
All-purpose wheat flour	1.33	0.37	0.95	1.00	0.62	61.3
Control (CPC)	1.72	1.09	0.82	2.18	1.09	77.5
Water (CPS)	2.16	1.22	0.93	2.75	1.37	77.0
Enzyme (CPE)	2.06	1.01	0.99	2.12	1.05	68.8

PSE 100:0: peak: 0.65 Pa·s, trough: 0.64 Pa·s, breakdown: 0.16 Pa·s, final: 1.35 Pa·s, setback: 0.76, pasting temperature: 10.7C; PSE 50:50: peak: 0.47 Pa·s, trough: 0.37 Pa·s, breakdown: 0.24 Pa·s, final: 0.77 Pa·s, setback: 0.03 Pa·s, pasting temperature: 7.1C.

CPC, whole-seed cowpea; CPE, cowpea soaked in α-galactosidase enzyme; CPS, cowpea soaked in water; RVA, rapid visco analyzer.

viscosity parameters (Zaidul *et al.* 2007). Hallen *et al.* (2004) reported that adding dry bean flours to wheat flour affected most dough pasting properties by suppressing the gelatinization property of the control flour. The high-protein content of cowpeas was shown to influence competition for water between protein and the starch network, reducing starch swelling during cooking, and changing the pasting characteristics of cowpea flour (Ayodele and Erema 2010).

Bread Properties

The bread-making potential of treated cowpea and plantain flours substituted into all-purpose wheat flour at 10 or 20 wt% substitution levels, and the properties of the resulting bread products are presented in Table 4. The bread substituted with cowpea flour had different physical features (Fig. 1). As the content of cowpea flour increased, indents on the cowpea control (CPC) increased (1b, 1e), browning increased with shrinkage for the enzyme-treated cowpea flour (CPE) with the hull (1c, 1f), while the water-soaked cowpea flour (CPS) increased in loaf size (1d, 1g). Compared with the bread made with the control plantain flour bread, the other breads with flour substituted with either treated cowpea showed similar properties in moisture content, water activity, density and textural firmness, with few exceptions. Cowpea (CPC and CPS) added to

TABLE 4. PROPERTIES OF ALL-PURPOSE WHEAT FLOUR BLENDED WITH COWPEAS OR PLANTAIN FLOURS AT 10–20 G/100 G

Flour	Substitution (%)	Moisture (%)	aw	Density (g/cm^3)	Firmness (N)	*L**	*a**	*b**	*L***	*a***	*b***
All-purpose wheat flour		37.73	0.96	1.40	5.93	60.79	–0.93	11.51	49.46	13.40	24.45
CPC	10	35.99	0.96	1.40	2.91	51.48	–0.44	8.22	41.13	13.05	22.01
	20	39.51	0.96	1.37	5.14	53.75	1.58	13.90	33.73	12.23	18.30
CPE	10	37.38	0.96	1.40	5.15	51.19	1.13	13.58	37.24	14.18	19.93
	20	37.81	0.96	1.36	6.16	50.03	4.07	18.88	30.14	12.31	14.44
CPS	10	38.21	0.96	1.39	4.29	57.53	0.17	11.55	43.73	14.84	23.77
	20	36.73	0.96	1.41	2.69	49.53	1.63	13.83	36.95	13.93	22.18
PLB	10	40.11	0.97	1.36	2.32	55.09	–0.41	9.11	53.19	12.61	29.50
	20	37.14	0.96	1.34	7.37	59.23	0.87	12.39	38.33	12.84	20.94
PC*	10	37.58	0.96	1.45	3.03	50.05	–0.23	6.81	47.68	13.95	27.06
	20	37.13	0.96	1.36	4.33	55.13	0.69	8.64	47.09	14.47	26.39
PLCA	10	37.05	0.96	1.46	3.20	58.31	–0.66	8.87	51.86	14.33	30.35
	20	40.73	0.97	1.37	5.93	56.99	0.74	11.85	49.76	13.70	27.96

PSE: cowpeas: MC: 1.44%, aw: 0.003, density: 0.02 g/cm^3, firmness: 1.41 N, *L**: 4.57, *a**: 1.61, *b**: 3.21, *L*** crust: 6.74, *a***crust: 1.75, *b***crust: 3.97. Plantain: MC: 1.47%, aw: 0.004, density: 0.05 g/cm^3, firmness: 1.82 N, *L**: 4.46, *a**: 0.91, *b**: 2.57, *L*** crust: 6.09, *a***crust: 1.64, *b***crust: 3.70.

CPC, whole-seed cowpea; CPE, cowpea soaked in α-galactosidase enzyme; CPS, cowpea soaked in water; PC*, plantain control; PLB, plantain blanched in 100C water; PLCA, plantain soaked in citric acid.

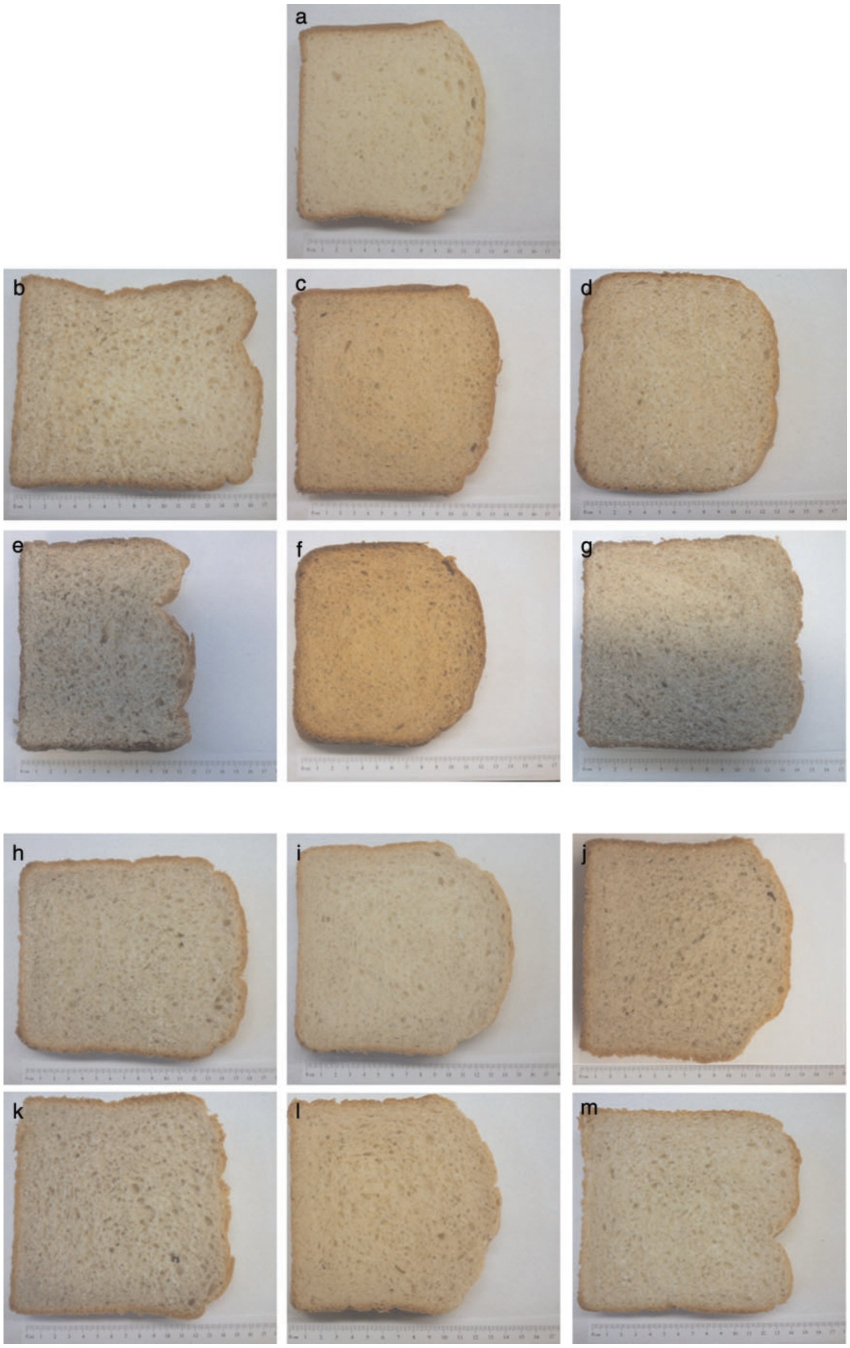

FIG. 1. (a) ALL-PURPOSE WHEAT FLOUR (b) CPC10, (c) CPE10, (d) CPS10, (e) CPC20, (f) CPE20, (g) CPS20, (h) PC*10, (i) PLCA10, (j) PLB10, (k) PC*20, (l) PLCA20, (m) PLB20 CPC, whole-seed cowpea; CPE, cowpea soaked in enzyme; CPS, cowpea soaked in water; PC*, plantain control; PLB, plantain blanched in 100C water; PLCA, plantain soaked in citric acid.

all-purpose wheat flour at 10% reduced firmness greatly. Prinyawiwatkul *et al.* (1997) showed that substituting cowpea flour for wheat flour up to a level of 20% produced bread with characteristics similar to control bread ($P > 0.05$). Bread containing 15% extruded cowpea flour was similar in moisture content, but denser; use of 30% extruded cowpea flour or 15 or 30% unheated cowpea flour produced breads that were not as acceptable.

The color properties of the bread shown in Table 4 that adding the plantain flours in all-purpose wheat flour bread did not change the color values of the internal bread structure nor the crust significantly from 100% all-purpose wheat flour bread, with the exception of a decrease in brownness (b^*) and lightness (L^*) using 10% PC* flour. The addition of cowpea flours showed some significant decreases in lightness (CPC and CPE) for both crust and

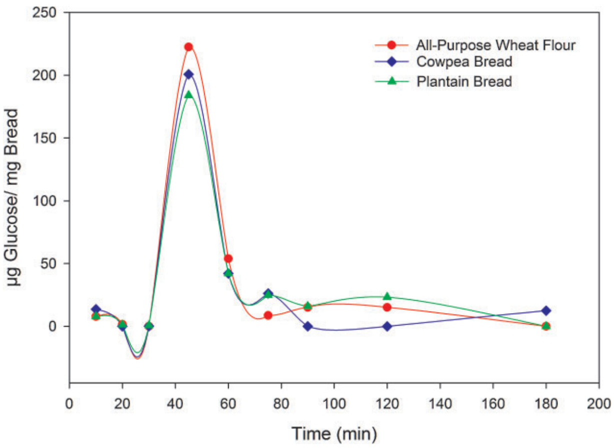

FIG. 2. INCREMENTAL GLUCOSE PRODUCTION DURING *IN VITRO* DIGESTION

internal structure, while CPE20 had significantly greater internal brownness but a less brown crust. In general, substituting plantain increased loaf size. Substituting with blanched plantain increased the loaf size with top indentation (Fig. 1j) on the bread surface (Fig. 1m), and resulted in increased browning. In a previous study, plantain flour substituted for whole-wheat flour had comparable sensory and nutritional qualities to the whole-wheat bread control, but the whole-wheat bread had highest hedonic mean scores in all the sensory attributes tested (Olaoye *et al.* 2006; Zakpaa *et al.* 2010). Olaoye *et al.* (2006) reported no significant differences in physical properties or appearance, general acceptability and sensory attributes between whole-wheat bread or the ones substituted with up to 15% plantain flours.

Glycemic Potential

In relative glucose assays, the incremental glucose production during *in vitro* digestion shows a pattern of highest glucose value for all-purpose white bread, followed by wheat bread substituted with whole-seed cowpea flour (CPS) at 20 wt%, and plantain flour (PLC) at 10 wt% (Fig. 2). The trend of relative glucose production showed faster breakdown of wheat flour, followed by cowpea and plantain.

While changes were observed (CPC10), substituting treated whole-seed cowpea flours into all-purpose flour bread did not significantly change available glucose, glycemic potential (RAG), SAG or the SAG glycemic potential (Table 5). Others have shown that in baking studies where cowpea flour was substituted into bread formulation at 15 wt%, the loaves produced were not significantly different from the 100% control wheat bread in appearance, color, aroma, flavor, texture, overall liking and acceptability (Phillips *et al.* 2003; McWatters *et al.* 2004). However, Nakamura *et al.* (2009) showed that cowpea proteins and starches and cell wall affected bread qualities. Blending cowpea with cereals improves the protein quality of the blend and allows the extension of cowpea into cereal-based bakery products and snack chips.

The apparent potential glycemic index values of bread made with the processed plantain flours are presented in Table 6. Processing of the unripe plantain meals alters the carbohydrate composition and thus may influence the glycemic index (both RAG and SAG) of the test foods (Wolever *et al.* 1986; Ramdath *et al.* 2004). The results suggested that blanched plantain starch (PLB10) is more slowly digestible than wheat starch, but the changes in Table 6 were not significant. In one human study, the glycemic response of processed unripe plantain lowered postprandial serum glucose concentration depending on preparation method, either boiled, fried or roasted; the roasted plantains had the lowest values (Ayodele and Erema 2010). Different factors can influence blood glucose response. The amount of carbohydrate as well as the type of carbohydrate in a food will influence its effect on blood glucose level (Sheard *et al.* 2004). These include the physical form of the food, degree and

TABLE 5. RAPIDLY AVAILABLE GLUCOSE (RAG) AND SLOWLY AVAILABLE GLUCOSE (SAG) VALUES FOR BREADS SUBSTITUTED WITH COWPEA AT 10–20 G/100 G

	RAG		SAG	
	μg glucose/mg bread	Glycemic potential RAG	μg glucose/mg bread	Glycemic potential SAG
All-purpose wheat flour	8.50	1.00	110.41	1.00
CPS10	6.46	0.76	112.80	1.03
CPS20	6.12	0.72	116.99	1.06
CPE10	8.13	0.96	101.36	0.91
CPE20	13.27	1.56	79.98	0.71
CPC10	2.76	0.33	103.21	0.95
CPC20	5.67	0.67	110.64	1.01

PSE: RAG: 3.20, GP RAG: 0.37, SAG: 19.14, GP SAG: 0.18.
CPC, whole-seed cowpea; CPE, cowpea soaked in α-galactosidase enzyme; CPS, cowpea soaked in water.

TABLE 6. RAPIDLY AVAILABLE GLUCOSE (RAG) AND SLOWLY AVAILABLE GLUCOSE (SAG) VALUES FOR BREADS SUBSTITUTED WITH PLANTAIN AT 10–20 G/100 G

	RAG		SAG	
	μg glucose/mg bread	Glycemic potential RAG	μg glucose/mg bread	Glycemic potential SAG
All-purpose wheat flour	8.50	1.00	110.41	1.00
PLCA10	7.29	0.86	126.01	1.15
PLCA20	8.79	1.04	114.48	1.04
PLC10	5.96	0.70	125.97	1.15
PLC 20	8.88	1.05	120.27	1.10
PLB10	4.47	0.53	114.10	1.04
PLB20	11.56	1.36	89.92	0.82

PSE: RAG: 2.28, glycemic potential, RAG: 0.27, SAG: 13.71, glycemic potential SAG: 0.17.

PC*, plantain control; PLB, plantain blanched in 100C water; PLCA, plantain soaked in citric acid.

type of processing, e.g., cooking method and time, amount of heat or moisture used (Pi-Sunyer 2002), type of starch (i.e., amylose versus amylopectin), and co-ingestion of protein (Manders *et al.* 2005).

CONCLUSION

To improve access to diverse nutrient-rich foods, developing dehydrated cowpeas and plantains will increase greater commercial utilization of these nutritious foods. Adopting these unique processes will reduce postharvest losses and will result in availability of plantain and cowpea flours that can be stored at ambient conditions for several months. Adding cowpea and plantain flour may provide sources of slowly digesting carbohydrates. The plantain and cowpea flours provide opportunity for using local raw materials for use in high-protein breads in developing countries. Differences in bread-baking properties depended on the amount of cowpea or plantain flour added.

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